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Study of midlatitude and artic aerosol-cloud-radiation feedbacks based on LES model with explicit ice and liquid phase microphysics.

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13. ABSTRACT *(Maximum 200 words)*

The proposed work is aimed at investigating the cloud-radiation feedbacks in midlatitude, subtropical, and high-latitude low level clouds. We will continue the study of marine stratocumulus clouds using LES simulations based on FIRE I and FIRE II/ASTEX observational data. The data will be used to validate the CIMMS LES model and to improve our understanding of the interaction between the microphysical, radiative, and thermodynamical processes. Validation of the model against observations will result in further refinement and improvement in the model physical and numerical formulation.

The modeling part of the research will be based on the CIMMS 3-D LES model of a stratocumulus cloud layer that includes an explicit formulation of aerosol and cloud drop size-resolving microphysics and radiation. The study of mixed phase clouds will use the new version of the CIMMS model which includes also explicit formulation of the ice-phase microphysics. Depending on the physics and the scale of the studied phenomena, the model may be also formulated in a 2-D framework with bulk treatment of microphysics.

In accordance with the FIRE III objectives, model simulations and data analysis will aim at the improvement of existing parameterizations of cloud and radiative processes in LES and large scale models.

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Study of midlatitude and Arctic aerosol-cloud-radiation feedbacks based on LES model with explicit ice and liquid phase microphysics

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Study of midlatitude and Arctic aerosol-cloud-radiation feedbacks based on LES model with explicit ice and liquid phase microphysics (N00014-96-1-0687)

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LONG TERM GOALS

The development and improvement of cloud microphysical and radiative parameterizations for use in mesoscale models

OBJECTIVES

Investigation of marine stratocumulus clouds microphysics and radiative processes using the CIMMS LES model with explicit microphysics and radiation. The data from FIRE II/ASTEX and MAST field experiments will be used to validate the model and to improve our understanding of the interactions between the microphysical, radiative, and thermodynamical processes.

APPROACH

The modeling part of the research will be based on the CIMMS 3-D LES model of marine boundary layer stratocumulus clouds that includes interactive radiation and explicit formulation of aerosol and cloud drop size-resolving microphysics. Depending on the physics and the scale of the studied phenomena, the model may be also formulated in a 2-D framework with bulk treatment of microphysics. Concurrent use of observational data to validate model simulations, as well as application of the model simulation results to test the hypothesis and conclusions of experimental data analysis, significantly enhances the research potential of both approaches.

WORK COMPLETED

To date, the CIMMS LES microphysical model has been verified in a case study of marine stratocumulus in the Northern Atlantic. Model successfully reproduced the observed thermodynamical, turbulent, microphysical and radiative structure of the cloud topped boundary layer. The case study also revealed the uncertainties in observations that need to be reduced in order to quantitatively assess the accuracy of model predictions. One component of this work is investigation of the interactions between aerosols and clouds. The model was applied to study the effect of aerosols on the cloud

microstructure by simulations of the ship track phenomena. In addition, a significantly enhanced version of the model that can track the aerosol particles as they are transformed by cloud processing, has also been developed. Finally, the work on parameterization of cloud microphysics resulted in a new five-moment scheme that has shown a significantly imporoved drizzle prediction than the previous schemes.

TECHNICAL RESULTS

(i) *Simulations of the aerosol-cloud-radiation interactions.*

Ship condensation trails are the most vivid examples of the effect of atmospheric aerosol particles on the marine stratocumulus cloud layer radiative properties. A large eddy simulation model with explicit microphysics has been used to study ship track formation under various boundary layer conditions. Experiments simulating the ship track formation in well-mixed and decoupled BL cases showed a rather efficient ship effluent transport in a well-mixed BL and a much slower transport in the decoupled BL case. In the latter case the stability of the transition layer, the buoyancy added by heat from the ship engine exhaust, and the surface heat flux are very crucial parameters. Simulations in various aerosol environments showed that ship track lasts longer in a clean boundary layer than in a polluted environment. Results support the hypothesis of drizzle suppression in the clean environment. The liquid water content inside the ship track may, however, be lower or higher than that of the background clouds, depending on the specific characteristics of the boundary layer, such as mixed layer depth, stability of the transition layer, and the concentration of cloud condensation nuclei.

The results in Fig. 1a, b show various microphysical variables covering part of the transition region from the ship track cloud to the unaffected background cloud. It is evident that a large number of CCN are activated in the ship track region ($x \approx 4$--6 km). In the 1st case (Fig. 1a), the LWP is significantly larger than the drizzle path (DP). The drizzle is very small both inside and outside the ship track and the cloud albedo differs insignificantly inside and outside the ship track (note that the drop concentration is multiplied by 0.5 in plot a). In the case of a cleaner air (Fig. 1b), the ship track significantly affects the cloud microstructure and albedo. The ship track drop spectra are relatively narrow and are composed mostly of small drops, whereas the drop spectra outside the ship track show many more bimodal distributions. Even though the LWP is high inside the ship track, the DP is significantly lower compared to the background cloud. The albedo clearly shows a substantial increase inside the ship track.

(ii) *Study of aerosol processing in stratocumulus clouds*

Prediction of the aerosol properties, and, consequently, the visibility and refraction of the marine boundary layer requires an accurate formulation of the aerosol processing by clouds. In addition, the heterogeneous chemical reactions which add nonvolatile solute to each cloud droplet, strongly depend

on the salt content and pH of the droplet. The CIMMS LES model was enhanced by introducing a 2-D distribution function which depends both on the drop mass and the mass of the solute inside each drop. Such formulation is now computationally feasible and allows tracking chemical species during the condensation, coalescence and evaporation cycles.

The statistics of the 2-D drop spectra at various cloud levels one hour into simulation is shown in Fig. 2a, b which depicts the cross-sections of the 2-D spectrum along the aerosol size. Fig. 2a shows the liquid water distribution integrated over all drop bins as a function of aerosol size. Near cloud base (z=0.2 km), the liquid water is more or less evenly distributed over all activated CCN categories. However, at higher levels the maximum of the LWC falls into the aerosol category which has the maximum number of activated CCN particles (dashed line with solid triangles in Fig. 2b).

The effects of processing on the aerosol spectra are summarized in Fig. 2b. The total aerosol spectrum (Aerosol+cloud drops) that would result if all cloud drops evaporate, is shown by the solid line. Part of CCN particles are activated by nucleation and part of aerosol particles remain as interstitial aerosol. The percentage of activated CCN particles varies depending on the CCN category. For example, for the CCN size 0.02 μm corresponding to critical supersaturation 0.39% about 55% of CCNs are activated. The partial activation is due to the large vertical velocity variance and, hence, the large variation in supersaturation at the cloud base. As a result, some number of large CCN particles (see, e.g., CCNs of about 0.04 μm which correspond to critical supersaturation of 0.2%) will remain unactivated at certain locations and exist as interstitial aerosols.

Fig. 2b also shows the change in particle numbers and surface area due to the cloud processing. The loss in terms of particle number is most significant for the smallest activated CCNs. For the largest aerosol categories, there is only a very small gain in concentration, as creation of one large aerosol particle may require hundreds or thousands of smaller aerosol particles to combine. However, the gain in the aerosol surface area is quite substantial and may significantly affect the aerosol optical properties.

(iii) *Parameterization of the cloud microphysical processes*

This long-term research program is designed to improve parameterizations of processes of drizzle formation and radiative transfer in stratocumulus clouds. The most commonly used Kessler-type parameterizations are based on prediction of cloud and drizzle water. Although computationally inexpensive, they lack the essential physical parameters important for accurate prediction of drizzle formation and evolution and its effects on thermodynamics. The developed at CIMMS new cloud microphysical parameterization is based on a five parameter scheme that predicts cloud and drizzle concentrations, cloud integral radius, in addition to cloud and drizzle liquid water mixing ratios. The parameter set allows a more accurate description of the sedimentation and autoconversion processes that are of prime importance for BL thermodynamical structure. The data from the CIMMS explicit

microphysical model verified against observations of marine stratocumulus in ASTEX and other field programs, was used to determine the important closure parameters.

Figure 3 shows comparison of some output data for simulations with explicit microphysical model, bulk two moments Kessler-type parameterization and the newly developed five moments CIMMS parameterization. Plots (a) and (b) show drop concentration (N_{cd}) and drop mean radius r_m for simulation of non-drizzling clouds in environments with high ("polluted") and low ("clean") aerosol concentrations. The prediction of the microphysical structure by the CIMMS bulk scheme is very close to that of the explicit model. In a simulation of a drizzling cloud layer shown in plots (c)-(e), the Kessler type scheme significantly distorts not only the microphysical, but also the dynamical structure, while the CIMMS parameterization was able to reproduce both the dynamical and microphysical parameters rather well.

RELATED PROJECTS

Theoretical and Observational Study of the Aerosol Effects on the Marine Stratiform Clouds Radiative Properties and Precipitation Efficiency. NOAA Office of Global Programs Grant NA37RJ0203.

The CIMMS LES model was developed and tested under the support from the NOAA Grant which will end in March of 1997.

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Liu, Q., and Y. L. Kogan, 1996: Study of aerosol processing in stratocumulus clouds using LES explicit microphysical model with the aerosol tracking option. 12th International Conference on Clouds and Precipitation, 19-23 August 1996, Zurich, Switzerland.

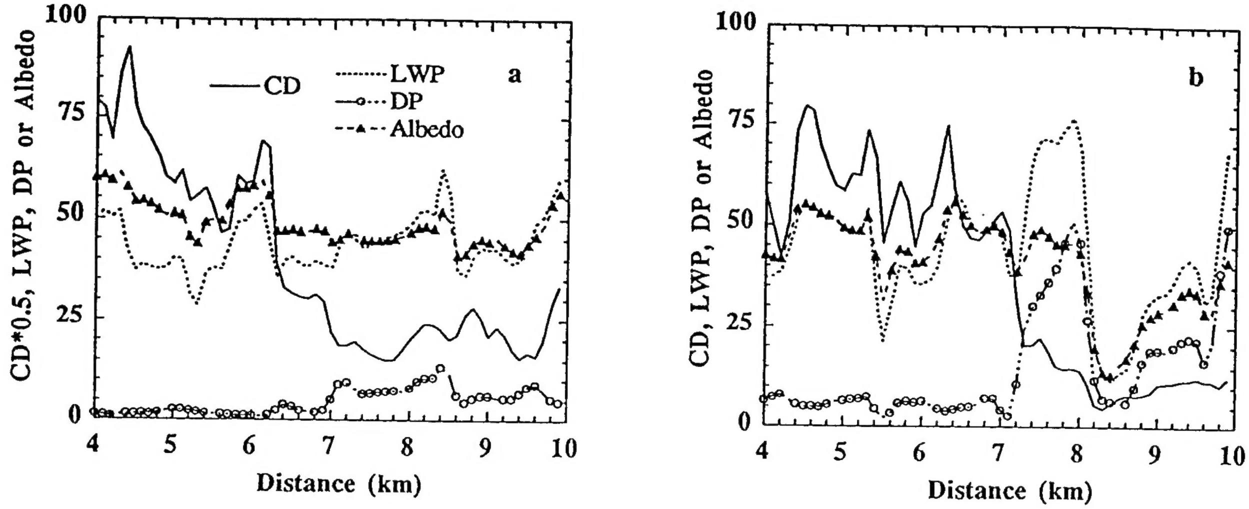

Fig. 1 Vertically averaged cloud drop concentration (CD, cm^{-3}), liquid water path (LWP, $g\ m^{-2}$), drizzle path (DP, $g\ m^{-2}$) and Albedo (%) in simulations with high (a) and low (b) background aerosol concentrations.

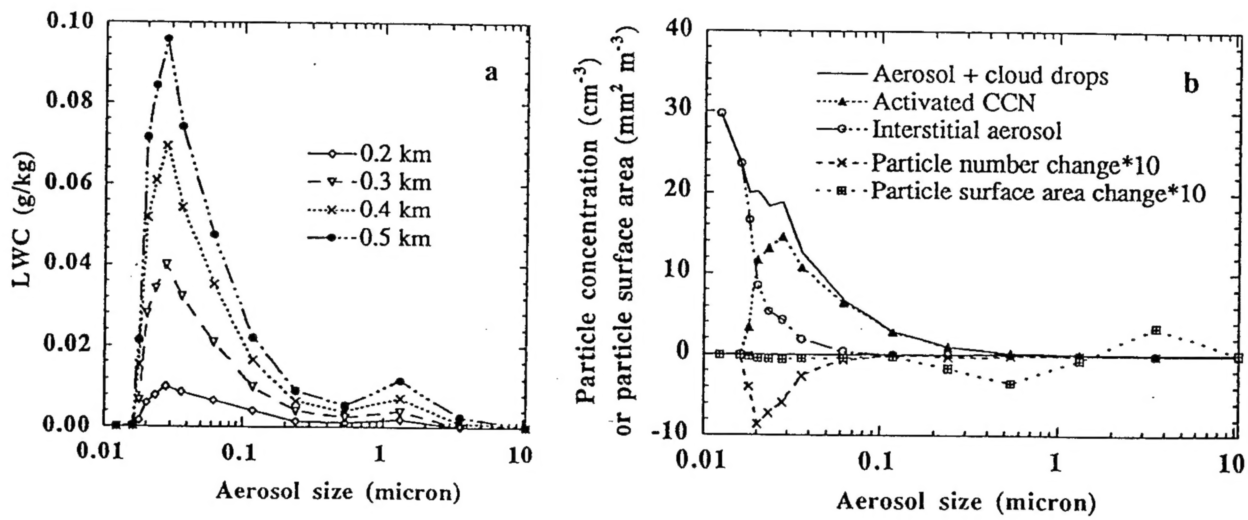

Fig. 2 Horizontally averaged LWC distribution as functions of aerosol size at different heights (a), and the summary of the effects of coagulation process on aerosol number and aerosol surface area (b).

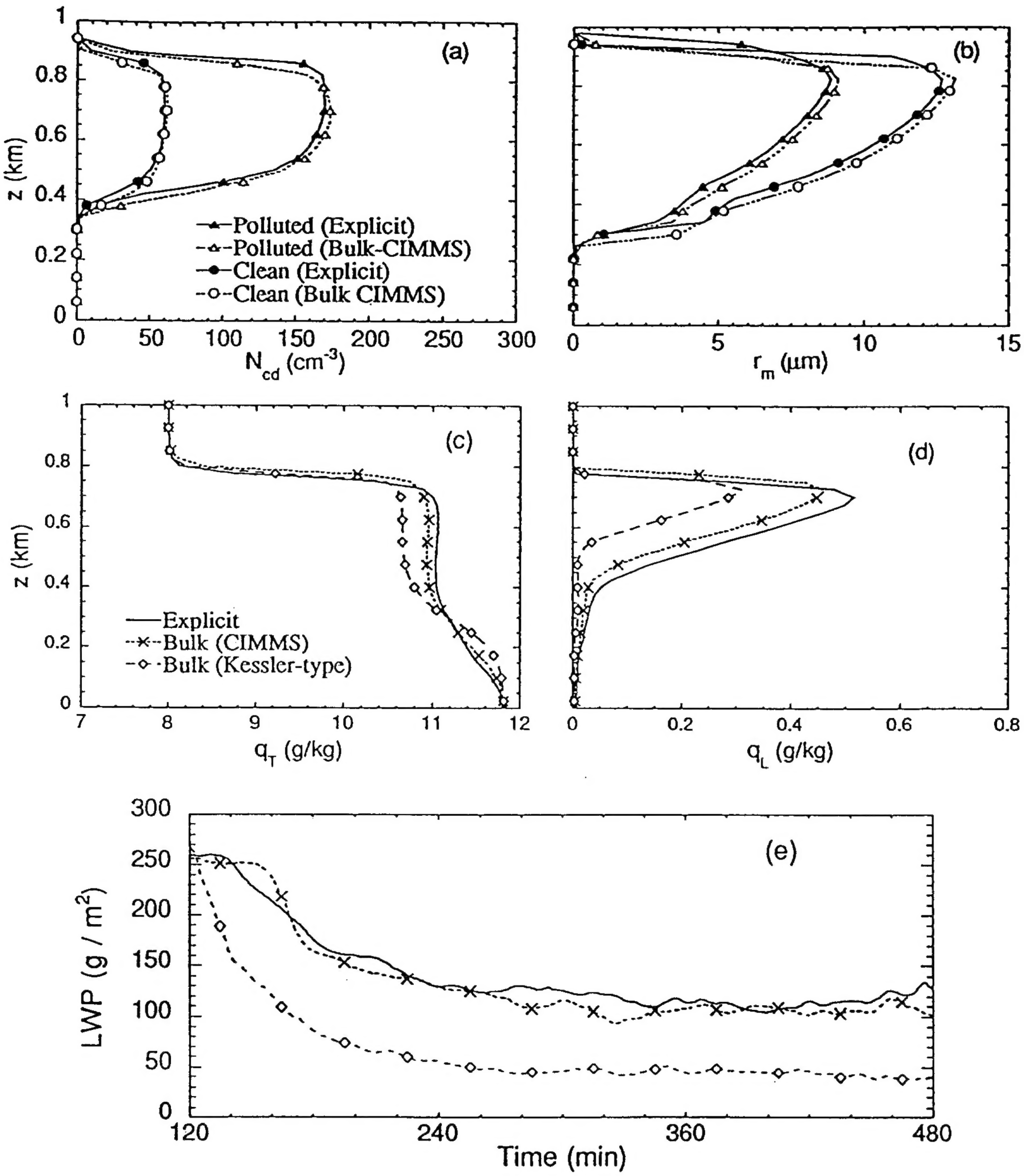

Fig. 3. Comparison of explicit microphysical model with bulk 2 moment Kessler-type and bulk 5 moment CIMMS microphysical parameterizations. (a) - cloud drop concentration; (b) - mean droplet radius; (c) - total water mixing ratio; (d) - liquid water mixing ratio; (e) - time series of liquid water path.